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Correlation Between Liquefaction Potential Using SPT and CPT Data in a Specific Site in Iran

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CORRELATION BETWEEN LIQUEFACTION POTENTIAL USING SPT AND CPT DATA IN A SPECIFIC SITE IN IRAN

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ABSTRACT

The geotechnical characteristic of the soil layers is one of the main factors influencing liquefaction potential of the ground. The standard penetration test (SPT), had been extensively used to measure the in-situ soil properties due to its simplicity and availability all over the world in the majority of the liquefaction studies. Nevertheless, it suffers from some shortcomings in comparison with another in-situ test called cone penetration test (CPT).
In order to compare the liquefaction potential evaluated based on the SPT data with those based on the CPT data, a specific site in the southern parts of Iran, have been selected and studied. The geotechnical characteristics of the site have been measured both from SPT and CPT methods, and for the same seismicity condition, the liquefaction potential was estimated using the SPT and CPT based evaluation methods. At the end some correlations were derived between the obtained results and their validities were discussed.

INTRODUCTION

Using the SPT data for evaluating liquefaction potential of the soil layers is nearly as long as the phenomenon was first recognized during 1964 Niigata earthquake. Seed and Idriss (1971) developed the first experimental method based on the SPT data to evaluate the liquefaction potential of the ground during heavy earthquakes. Since then , although the original SPT based evaluation method has been modified and promoted extensively and other evaluation methods have been suggested and used by many researchers , the SPT-based methods have become increasingly common and popular.

One of the main reasons is the simple device and easy technique associated with the standard penetration test. Also the availability of the equipment and operating system is another factor making it more routine in practice. Further more the vast majority of geotechnical investigations carried out in site projects in the past, have been involved with the SPT, and considerable data can be collected and used in these regions. Nevertheless, there are some deficiencies and shortcomings with the SPT, the most important of which can be summarized as follows:

- The repeatability of the test can not be guaranteed.
- The soil profile can not be detected continuously.
- The pore pressure can not be measured during the test.
- The sensitivity of the device to changing soil profile is sometimes poor.
- The influence of pore pressure fluctuations due to blow effects of the system on the test results can not be considered.
- The theoretical interpretations about the test results can not be implemented.

Although the effect of these factors on the accuracy and reliability of the test results are not the same, some of them may considerably influence the measured data. In contrast to SPT, the CPT is also another in situ testing device and technique that can be used for the same purpose, without having the above mentioned problems. However, the complexity of the system and the more energy and time consuming of operations relative to the SPT, have caused it less popular and common in practice.

Yet, there are some liquefaction evaluation methods based on the CPT data, in which the geotechnical characteristics of soil obtained from tip resistance and skin friction of the device can be used more accurately. Since extensive efforts still are being done for microzoning different cities against liquefaction using the existing SPT data all over the country, in this study a specific site has been selected to compare the liquefaction potential estimated by using SPT and CPT data. This may clarify the level of reliability and accuracy of the SPT based methods. The specifications of the selected site and liquefaction potential evaluation methods used in this study are described in the following sections.

THE SELECTED SITE FOR STUDY

There are some initial requirements for the site to be under consideration in this study. The results of the SPT and CPT studies must have been available and the points at which these tests are carried out can not be far from each other. Also there must have been some liquefaction potentials observed in the site at least according to one or more methods based on the SPT and CPT data. Furthermore the test should have been done in the site by an acceptable level of accuracy and satisfactory.

Considering these facts, a specific site in the southern parts of Iran has been selected. The site was located on the Bandar-Abbas near the coastal region of the Persian Gulf and belongs to the Almahdi aluminium producing factory. The ground in this area is usually consisted of deposits belonging to third and fourth geological periods.

The soil layers in the site are between sandy silts to silty sand and can be classified as fine granular soils (PI≤5%). The water table in the site is located at 1.5 m. depth, and the densification of the top layers can be categorized between medium to loose. The seismicity of the regions is relatively high compared with other area of the county. The positions of the studied site is shown in fig. No.1.

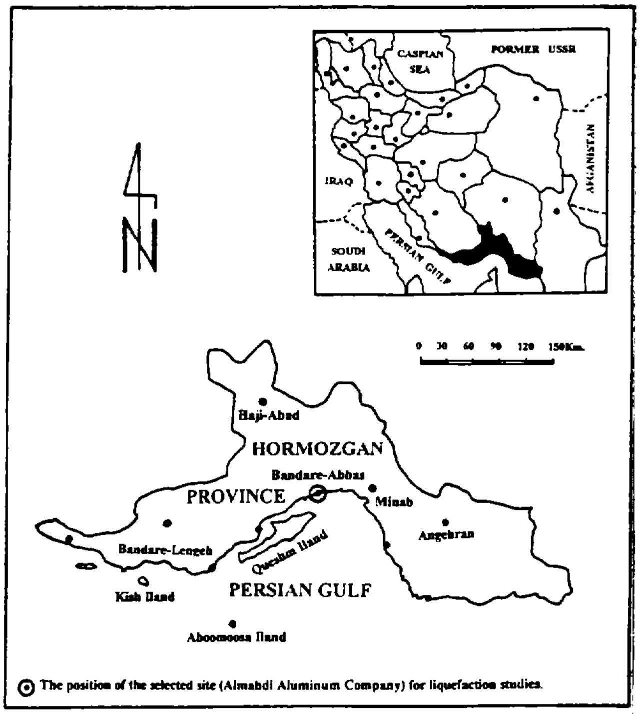

Fig. 1. The general plan of the region with the selected site for liquefaction studies.

THE COLLECTED SPT AND CPT DATA IN THE SITE

The existing SPT and CPT data belonging to different depths and layers were collected. The SPT data have been taken nearly every 1.5-2 meters and also at changing the soil profiles. The position of the water table and some physical properties of the layers were also recorded and used in the studies. Some main assumptions and facts in connection with the SPT data were made, the important of which are as follows:

- Since there has not been definite information about the exact position of the SPT data along the soil profile, a kind of moment in the ±0.5m depth has been estimated, and used as an average SPT value for the whole distance.
- Some kind of interpolation was carried out to fill the gaps between particle size and fine contents that were not reported in the borehole logs.
- The plasticity indices for all selection points were in the range of PI≤15%, and the cyclic resistance ratios (CRR) for points having 5≤PI≤15 have been considered to increase linearly from 0 to 10% (According to the comments of some researchers in the NCEER workshop in 1997).
- Since the suggested method by Robertson & write (NCEER-workshop 1997) for points having q_{1CN} < 1 Mpa and or (N1)60<5 can not be valid, in this study 15 points [having (N1)60<5] and 6 points [Having q_{1CN} <1Mpa] were ignored. (Youd & Gilstrap 1999)

The total points having acceptable CPT and SPT data in this site were 45. A typical SPT and CPT belong to the site under study is presented in fig. No.2.

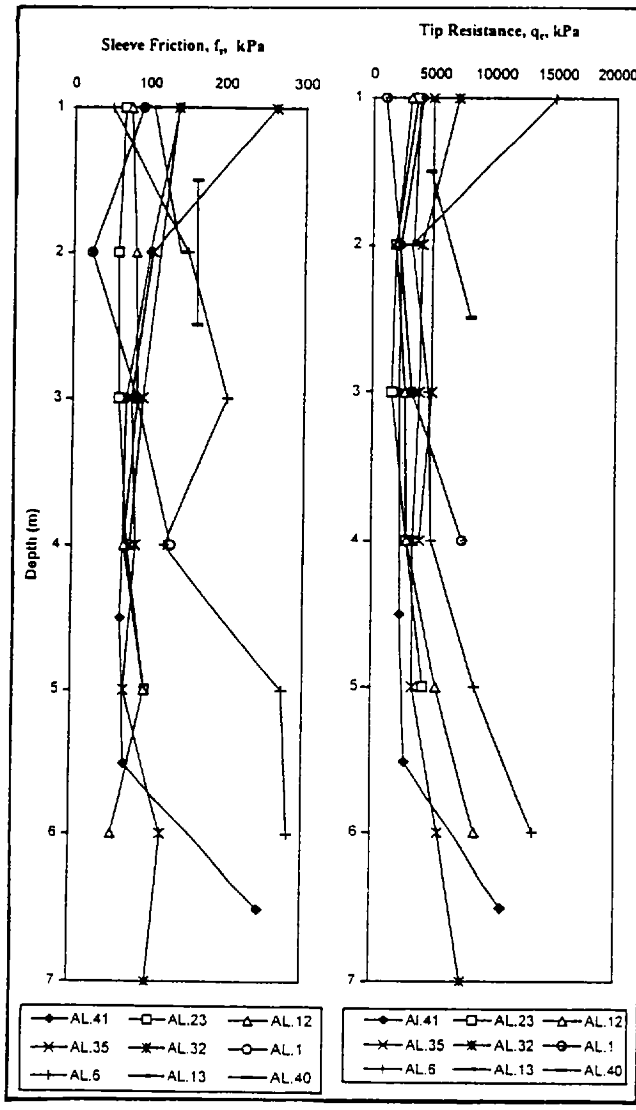

Fig. 2. Typical CPT data of the site used in the study.

THE LIQUEFACTION EVALUATION METHODS USED IN THE STUDY

Although there are different methods for evaluating liquefaction potential of the sand layers using SPT and CPT data, in order to avoid scattering the results, the two of them which have proven to be the most appropriate one, and have been used in many cases by different researchers, have been selected and used as below:

I.Robertson and Wride method (1997)

This method is in fact based on the method, originally suggested by Seed and Idriss (1971). In this method the values of tip resistance of the CPT and also the number of SPT blows, are corrected in terms of the fine content according to one of the two following ways:

$(N_1)_{60Cs} = Ks(N_1)_{60}$ (1)

In which:

$Ks=0.025\ Fc+0.875$ for $\%5 \leq Fc \leq 35\%$,& $PI \leq 5\%$

$Ks=1$ for $Fc \leq 5\%$, & $PI \leq 5\%$

and the tip resistance of the CPT can be corrected by these equations:

$Kc=1.0$ for $Ic \leq 1.64$ (2)

$Kc=-0.403\ Ic^4+5.581\ Ic^3-21.63\ Ic^2+33.75Ic-17.88$ for $Ic>1.64$ (3)

In the second way which has been developed in 1997, the following equations can be used to correct the SPT numbers and also the CPT tip resistance, respectively:

$(N_1)_{60Cs} = \alpha+\beta\ (N_1)_{60}$ (4)

In which:

$\alpha=5.0$, $\beta=1.0$ for: $Fc \leq 5\%$

$\alpha=\mathrm{Exp.}\ [1.76-(190/Fc)^2]$, $\beta=[0.99+(Fc^{1.5}/1000)]$ for: $\%5<Fc<35\%$

$\alpha=5.0$, $\beta=1.2$ for: $Fc \geq 35\%$

And for CPT:

$(q_{CIN})cs = q_{CIN} + \Delta(q_{CIN})$ (5)

in which :

$\Delta(q_{CIN}) = K_{CPT}\ (q_{CIN})_{cs}$

$\Delta(q_{CIN}) = [K_{CPT}/(1-K_{CPT})]\ (q_{CIN})$

$K_{CPT} = 0$ for: $AFC \leq 5\%$

$K_{CPT} = 0.0267(AFC-5)$ for: $\%5<AFC<35\%$

$K_{CPT} = 0.8$ for: $AFC \geq 35\%$

Where AFC is the Apparent Fine Content, to be calculated by the following equation (Robertson & Wride, 1997):

$Ic< 1.26$ $AFC= 0$

$1.26 < Ic \leq 3.5$ $AFC\ (\%)=1.75\ I_C^{3.25}$

$Ic>3.5$ $AFC\ (\%)=100$

II. Suzuki et.al. Method (1997)

This method is based on the CPT data, and has been developed according to instrumented data in four heavy earthquakes hitted about 68 regions in Japan. The recommended curve by Suzuki et.al. (1997) is a little more conservative than that suggested by the NCEER workshop. If the soil characteristics are defined in terms of soil behavior type Index, I_C, the liquefiable and unliquefable boundary recommended by Suzuki et.al. can be used.

COMPARISON BETWEEN ANALYSIS RESULTS BASED ON SPT AND CPT DATA

The comparison between the results of analysis has been made in terms of calculated safety factors, based on SPT data and CPT data belong to the site under consideration. A linear regression has been used to correlate the analysis results and the correlation factors have been considered as the degree of relationship between these two methods. The safety factors against liquefaction using the NCEER method (1997) for the site have been calculated and shown in fig. No.3.

As can be seen the results are very scattered. If five points, that have the absolute differences between their safety factors greater than 1.5, (ABS>1.5), are ignored, the correlation factor will increase up to 2.5 times, but this factor is still very small. The above points only cover 10% of the all information points. Even ignoring the points of having ABS>1.0, i.e. considering 77% of information points, the correlation factor is still very small, but shows greater changes compared with the former state (fig. No.4).

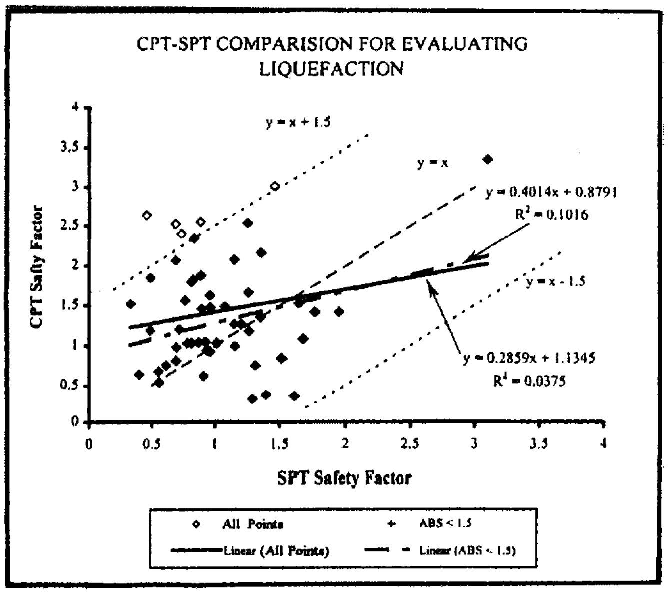

Fig. 3. Comparison between safety factors against liquefaction using all collected data and NCEER method (1997).

The results of analysis of SPT data using NCEER method (1997) are compared with the results of analysis of CPT data using Suzuki (1997) method in fig. No.5. Again as can be seen, although considerable changes happen in correlation factor by ignoring the points of having ABS>1.5 (Some changes from $R^2 = 0.0375$ to $R^2 = 0.1062$), it still lies in a very small range.

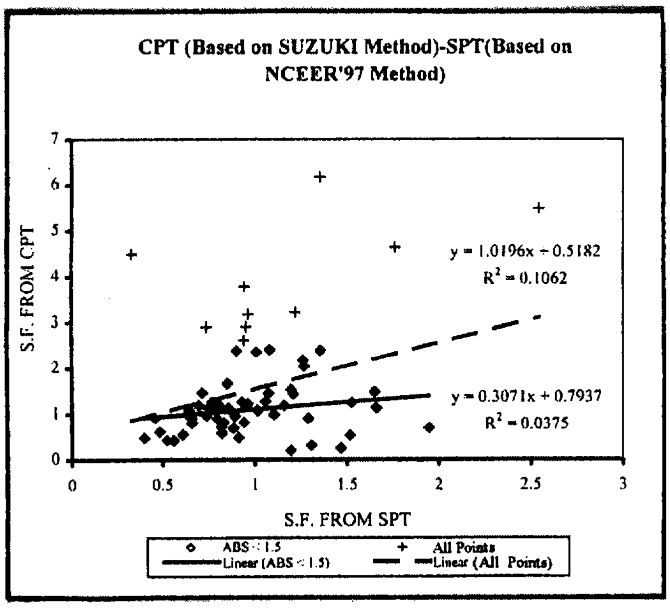

Fig. 5. Comparison between safety factors against liquefaction using SPT based NCEER and CPT based Suzuki et al. methods.

According to the general results of this study, as far as the fine granular soils are concerned, in spite of highly scattered results, an overall conclusion can be derived, in the way that the liquefaction potential evaluation of the ground by CPT data would be more conservative than that obtained by SPT data (Fig. No.5). As it was observed in this study, the selected site was in the sandy silt to silty sand ranges, thus the results can be valid only for these fine granular soils. This classification can be also confirmed by CPT data belonging to the site.

COMPARING THE RESULTS WITH OTHER RESEARCHER'S

Different researchers have focused on liquefaction potentials of susceptible soils in a comparative study by using both SPT and CPT of the ground layers. Among them Youd and Gilstrap (1999) carried out extensive investigations to correlate between liquefaction safety factors based on CPT and SPT data of several sites. They used Robertson-Wride (NCEER workshop 1997) method and obtained important results in their studies.

The information points used, mainly belonged to the sites of clean sand to silty sands. It can be seen that (Fig No.6) for FC>50%, the suggested graphs by Robertson and Wride give the predicted FC values less than its real value in terms of I_C. This is clear in Youd & Gilstrap studies as well. It has to be noted that the Suggested FC-I_C relation by Robertson- Wride is an average curve, which has been, fitted to an extensive range of many informations points.

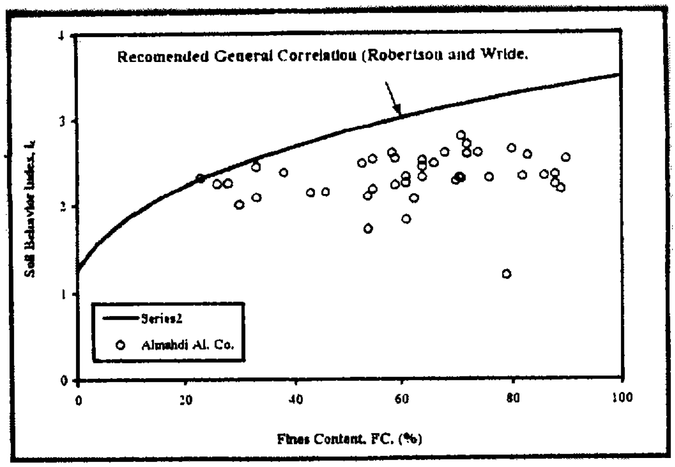

Fig. 6. Comparison between Ic-FC relation in the selected site and that suggested by Robertson and Wride (1997).

In the comparison made between liquefaction safety factors estimated based on the CPT and SPT data by Youd & Gilstrap, also a large scattering ($R^2 = 0.5864$) was shown, nevertheless, ignoring the points of having ABS>0.4 and concentrating on the 77% of the remaining points, the correlation factor would be of high value ($R^2 = 0.914$).

The main cause of this difference between the results of Gilstrap & Youd and the results of the current study may be attributed to the quite fine nature of the selected site in this piece of research. As noted earlier the soil layers involved in this study belonged to the southern region of Iran, and the surfacial layers which are susceptible to liquefaction mainly consisted of fine sand to sitly material which considerably influence the penetration strength in the standard penetration and cone penetration tests.

SUMMARY AND CONCLUSIONS

In order to find a correlation between liquefaction evaluation results based on the SPT data and CPT data, a specific site was selected. The site located on the Bandar-Abbas near the coastal region of the Persian Gulf in the southern part of Iran (Almadi Al.Co. site).The geotechnical characteristics of the site were measured using both in situ tests; SPT and CPT up to about 25 meters depths separately.

The soil fabrics were mainly non-cohesive fine materials ranging from silty sands to sandy silts. The water table was relatively high and the seismicity of the region was classified as the high risk area in the country.

The liquefaction potential of the site was evaluated, using two different methods, namely Robertson & Wride (1997) method and Suzuki et al. (1997) method. The safety factors of the site against liquefaction were estimated using the two mentioned methods for SPT data and CPT data separately.

The results were plotted against each other and the correlation between the safety factors calculated based on the SPT data and the CPT data were obtained. Although the correlation factor was found to be very small and the results were highly scattered, it could be concluded that the liquefaction evaluation method based on the CPT data shows more conservative results compared with those based on the SPT data. To get more accurate and quantitative results much more sites and information points are required.

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